

# On the influence of shrub height and expansion on northern high latitude climate

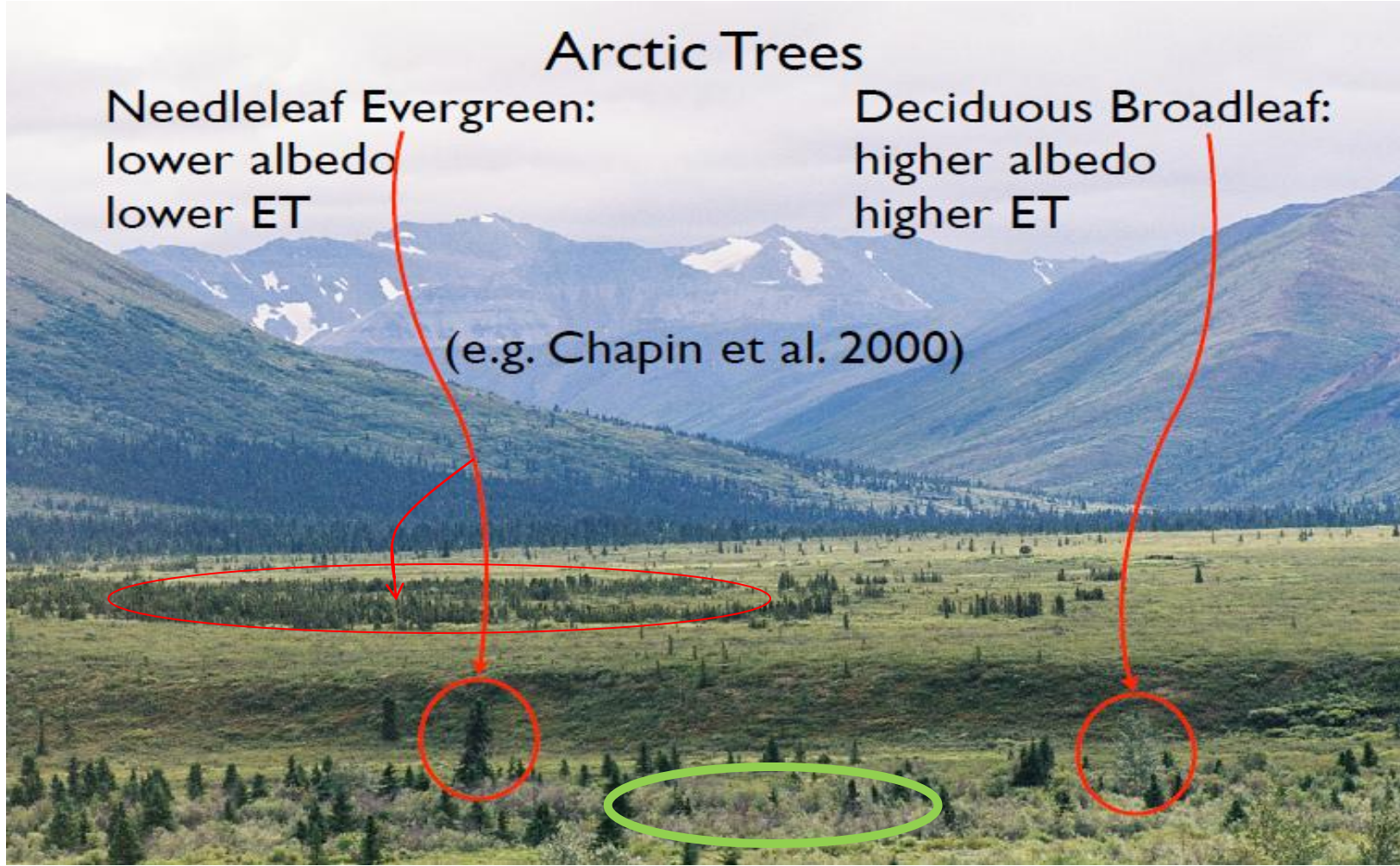
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## Rapid changes in arctic vegetation are expected in response to the pronounced warming climate

### Tundra-to-forest conversion



- Expanding evergreen forest amplify warming through an **albedo feedback** (Bonan et al. 1992, Foley et al. 1994, Levis et al. 1999)
- Expanding deciduous forest cause an **additional evapotranspiration-induced GHG feedback** (Swann et al. 2010)
- Widespread tundra-to-forest conversion mainly predicted by equilibrium vegetation models; unlikely to occur in the current century (Chapin et al. 2005)

In contrast, there is no experiment on the possible tundra-to-shrub conversion

## Multiple evidences documenting the increase in deciduous shrub abundance and size

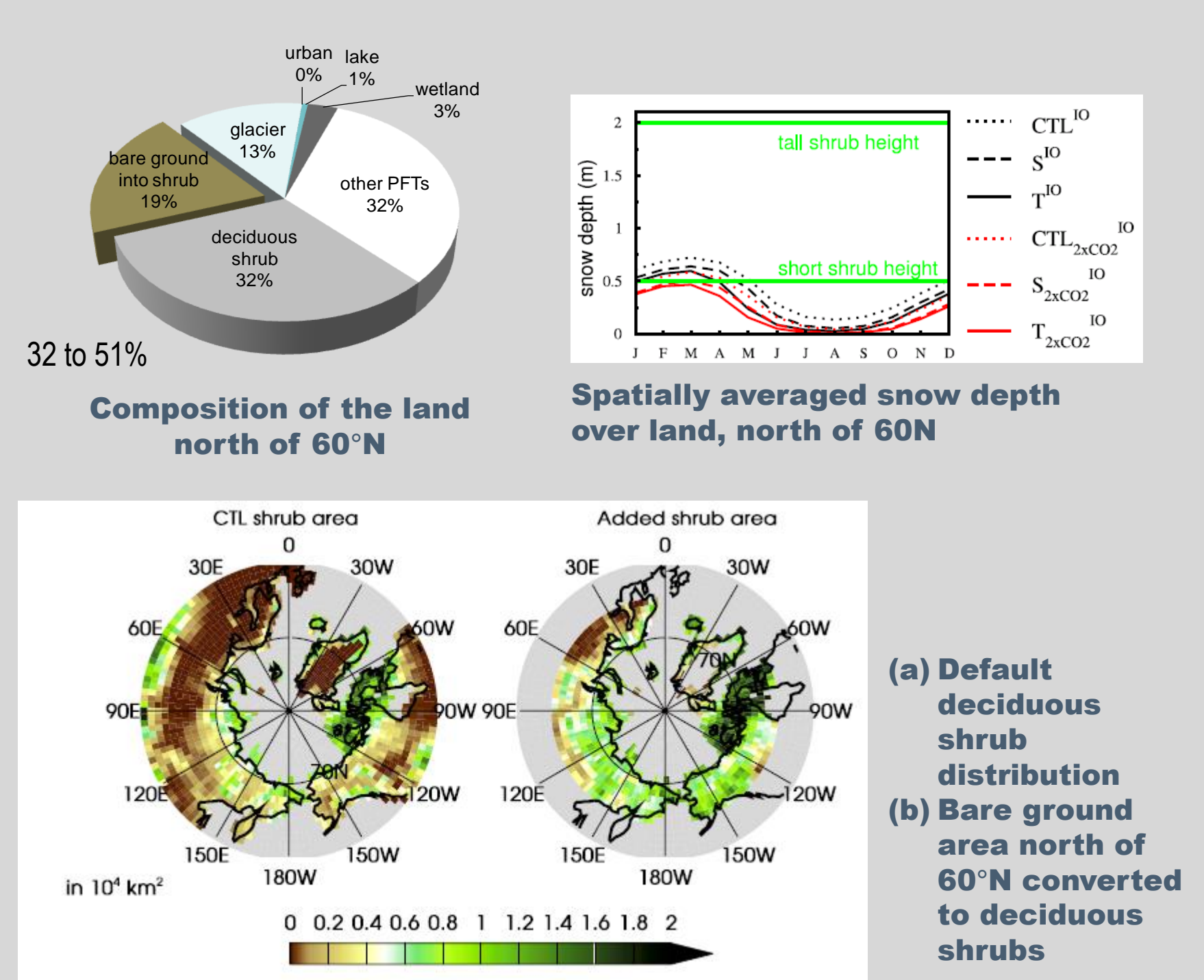


- Photographs, transect studies, satellite indices, and local testimonies, etc...
- Shrub area increased by 1.2% decade<sup>-1</sup> since 1950 in Northern Alaska (Sturm et al. 2001)
- Small shrubs already present in most tundra areas, ready to grow under more favorable conditions (field studies, warming treatments, past climate)
- Shrubs can promote their own development by favoring snow accumulation and soil microbial activity (Sturm et al. 2005)
- Tall shrub predicted in low shrub region by plant dynamics model under a 2°C warming (Epstein et al. 2007)

## Climate model experiments to estimate the effects of shrub expansion on climate

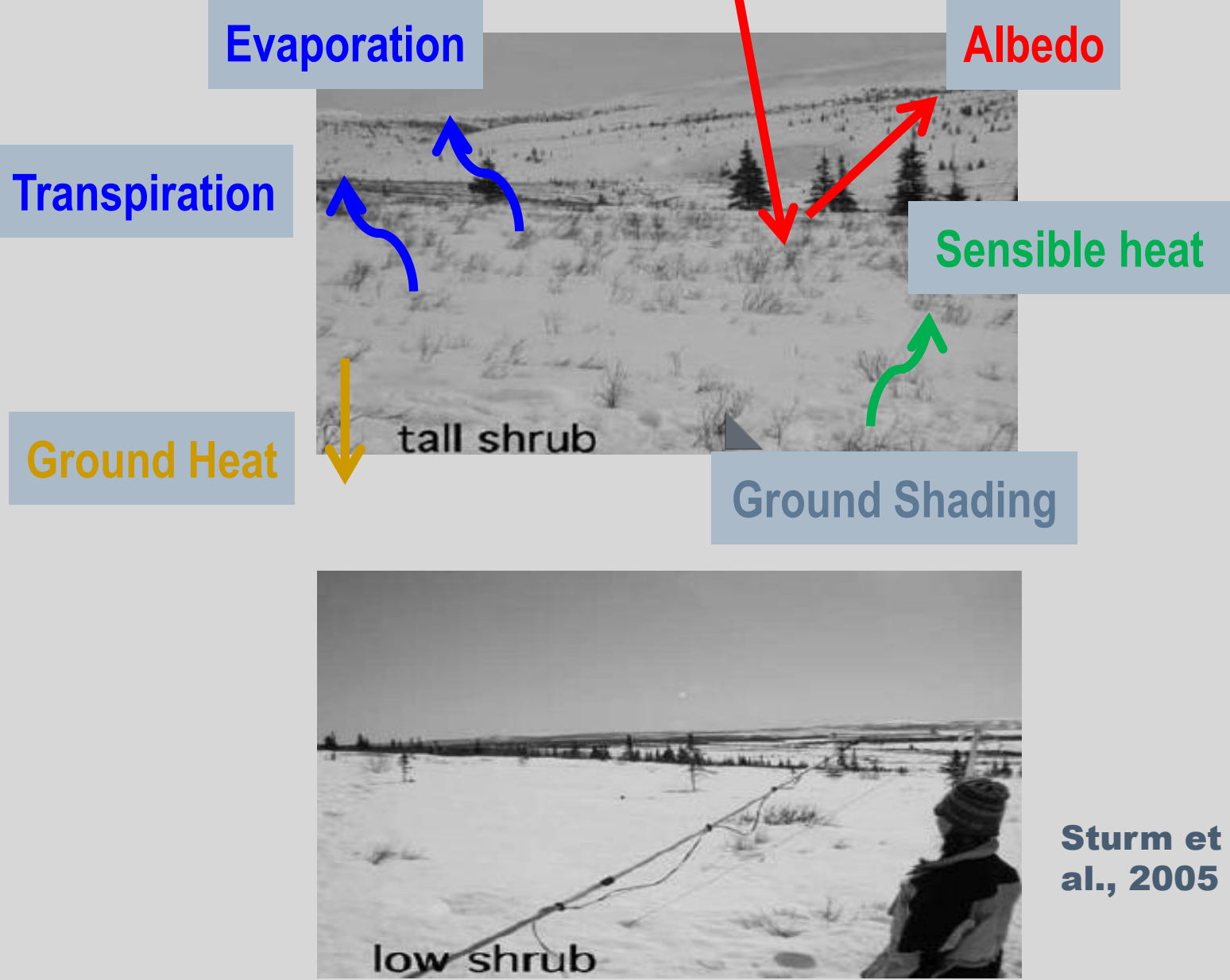
### Experimental design with CESM1 (1.9°x2.5°)

Forcings	short shrubs replace bare ground (S)	tall shrubs replace bare ground (T)	Objective
1xCO <sub>2</sub> fixed ocean (FO)	(S-CTL) <sup>FO</sup>	(T-CTL) <sup>FO</sup>	Effect of adding shrubs
1xCO <sub>2</sub> interactive ocean (IO)	(S-CTL) <sup>IO</sup>	(T-CTL) <sup>IO</sup>	Added effect from indirect ocean / sea-ice feedbacks
2xCO <sub>2</sub> interactive ocean (IO)	(S <sub>2xCO<sub>2</sub></sub> -CTL) <sup>IO</sup>	(T <sub>2xCO<sub>2</sub></sub> -CTL) <sup>IO</sup>	Added effect from 2xCO <sub>2</sub>



### Expected feedbacks

- Feedbacks: albedo; evapotranspiration



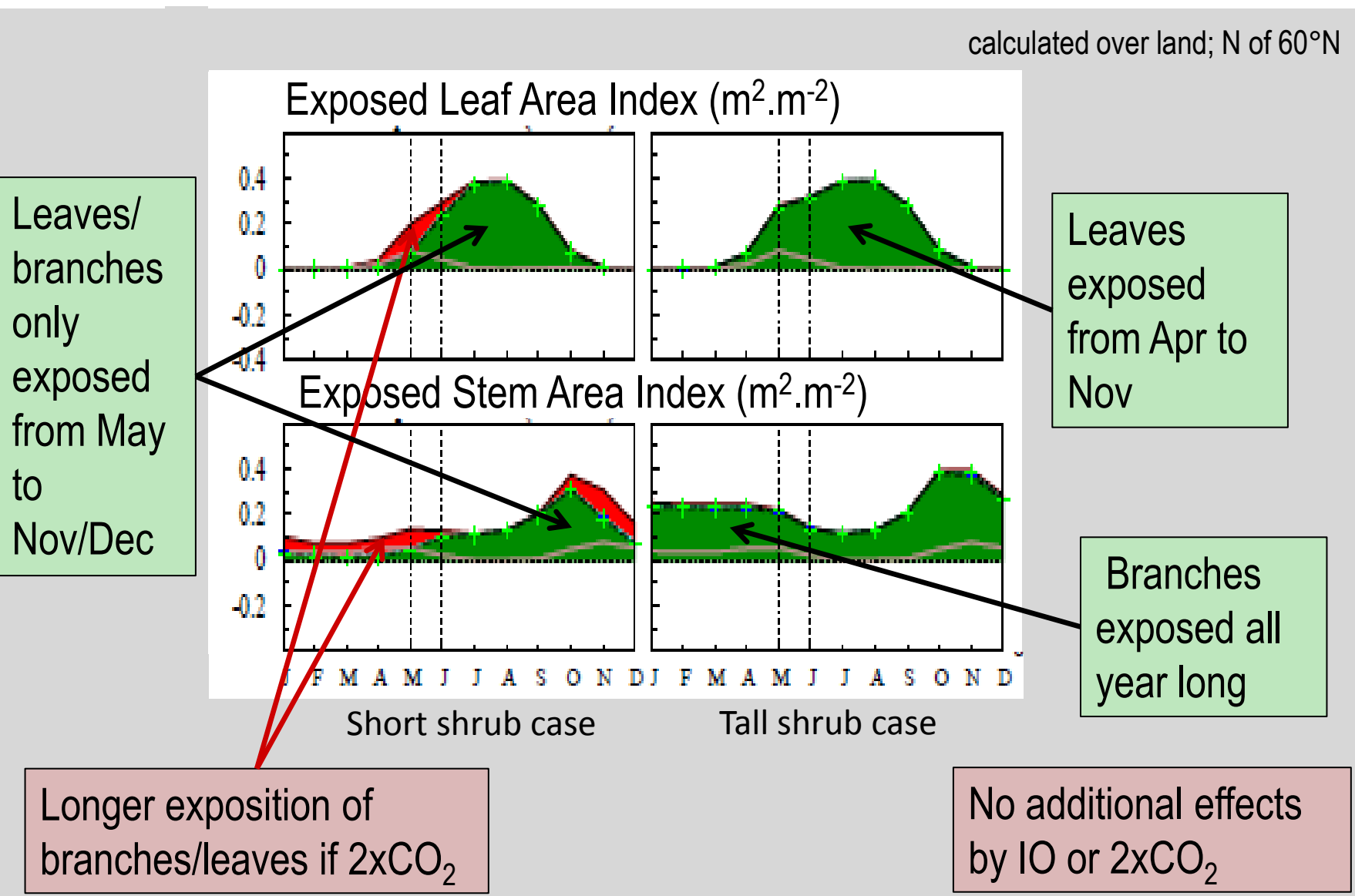
- Shrub height can affect their timing

### Questions

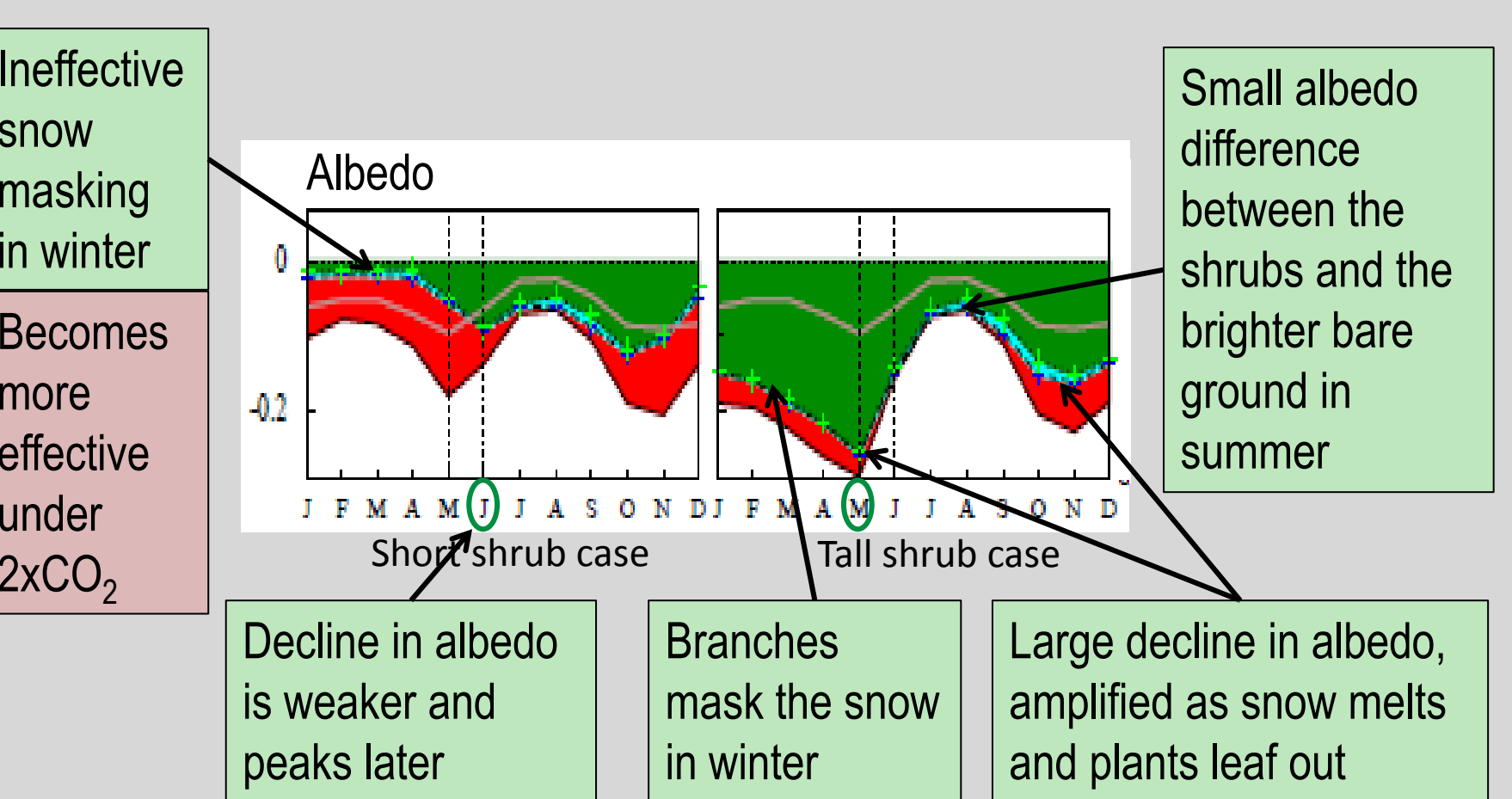
- What are the biophysically-induced effects of shrub expansion on boreal climate?
- Are they sensitive to the height of shrubs?
- What are the effects on permafrost?

## Shrub expansion causes a warming through albedo & transpiration-induced water vapor feedbacks

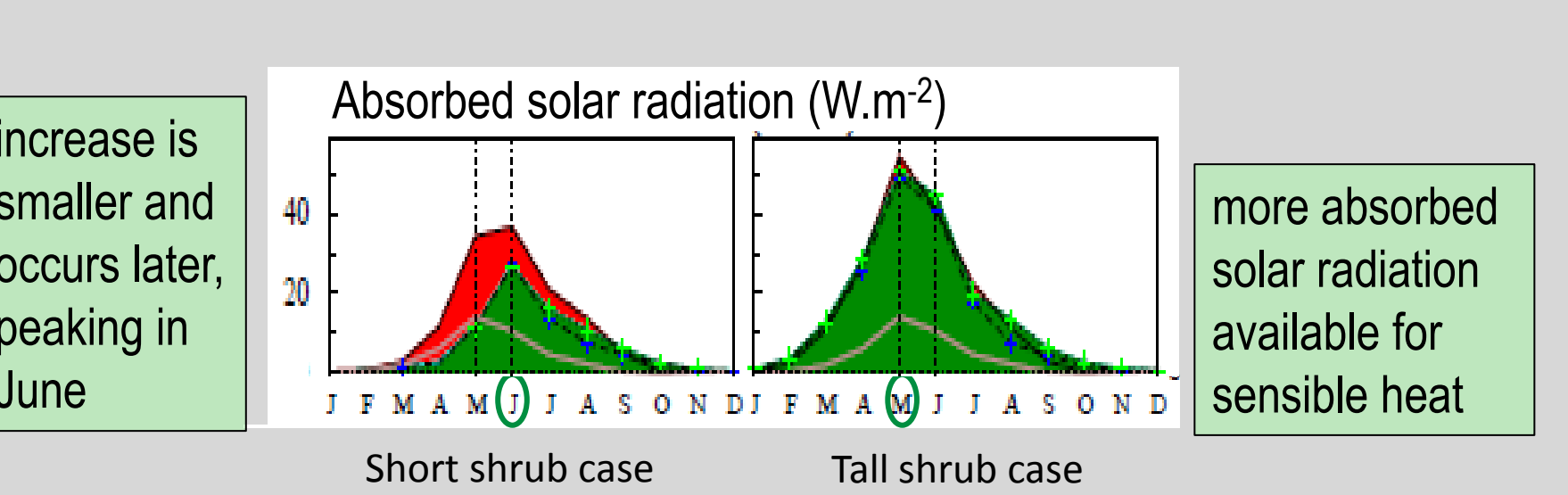
### Seasonal evolution of the vegetation protruding above the snow



### Exposed vegetation impacts the seasonal evolution of albedo



### This affects the energy balance when the sun returns



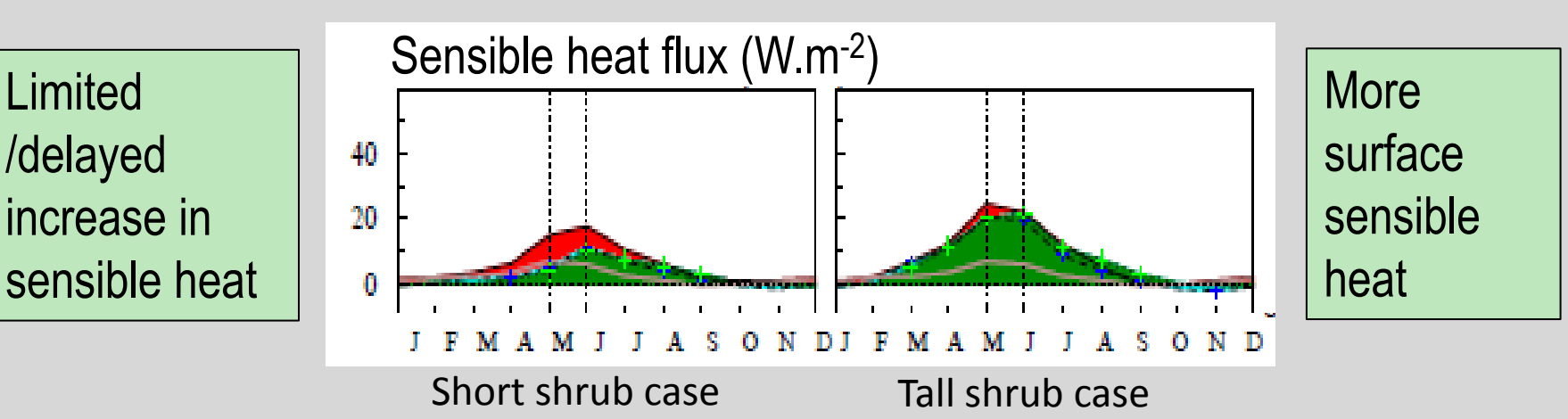
## Acknowledgements

We warmly thank Mac Post for helping with the experimental design regarding the height of shrubs, and Charlie Koven and Abby Swann for several fruitful discussions. This work was sponsored by the US Department of Energy (BERDOE)-funded IMPACTS (Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions) project. The CESM model, supported by the National Science Foundation and BER-DOE, has been run at the National Energy Research Scientific Computing Center, supported by BER-DOE under Contract DE-AC02-05CH11231

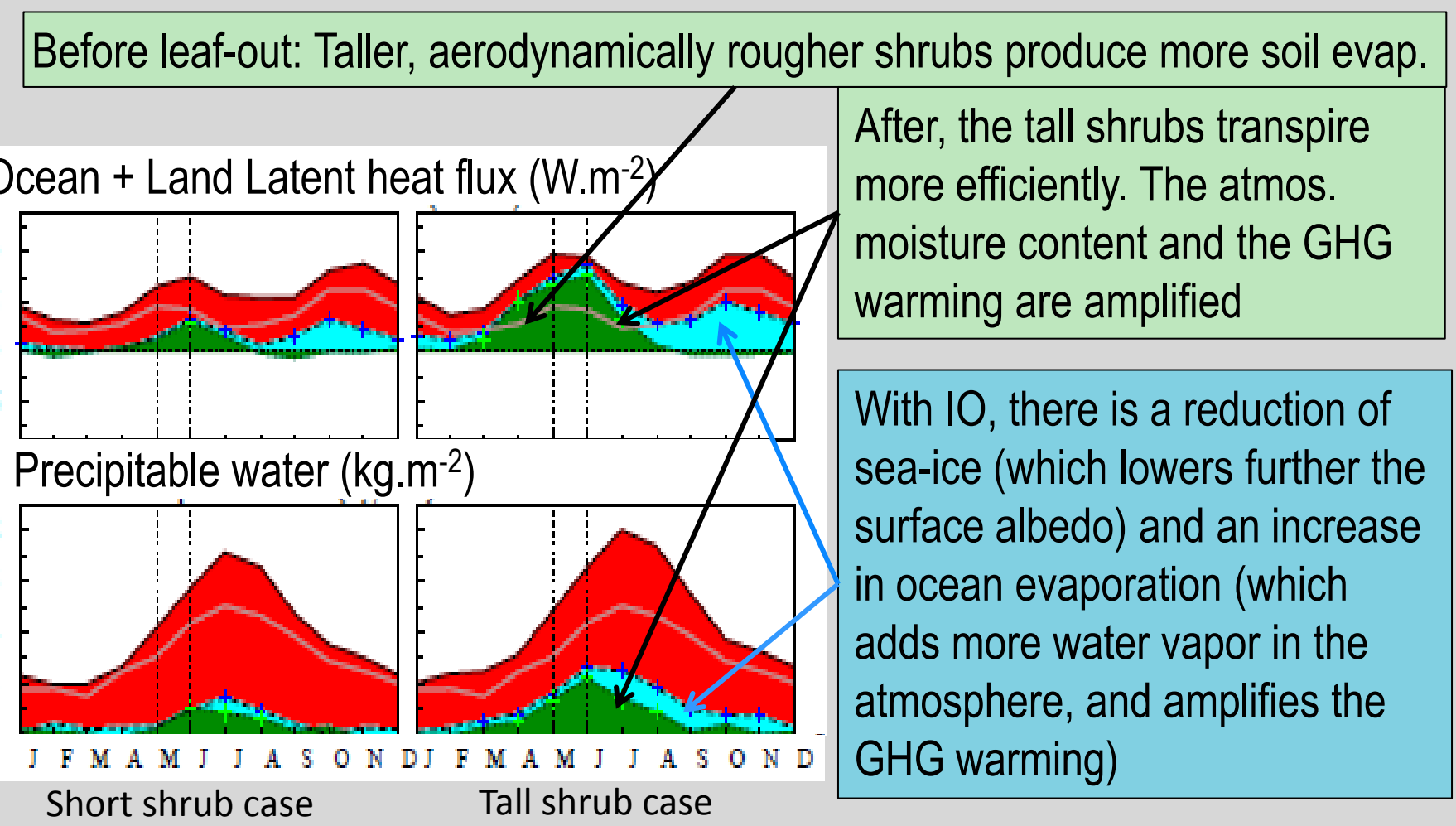
Reference: Bonfils, C., T.J. Phillips, D.M. Lawrence, P. Cameron-Smith, W.J. Riley, Z.M. Subin, 2011: On the influence of shrub height and expansion on northern high latitude climate. *Environmental Research Letters*, 7, 015503, 2012, doi:10.1088/1748-9326/7/1/015503. <http://stacks.iop.org/1748-9326/7/1/015503>.

## With short shrubs, both albedo and evapotranspiration feedbacks are weaker and delayed

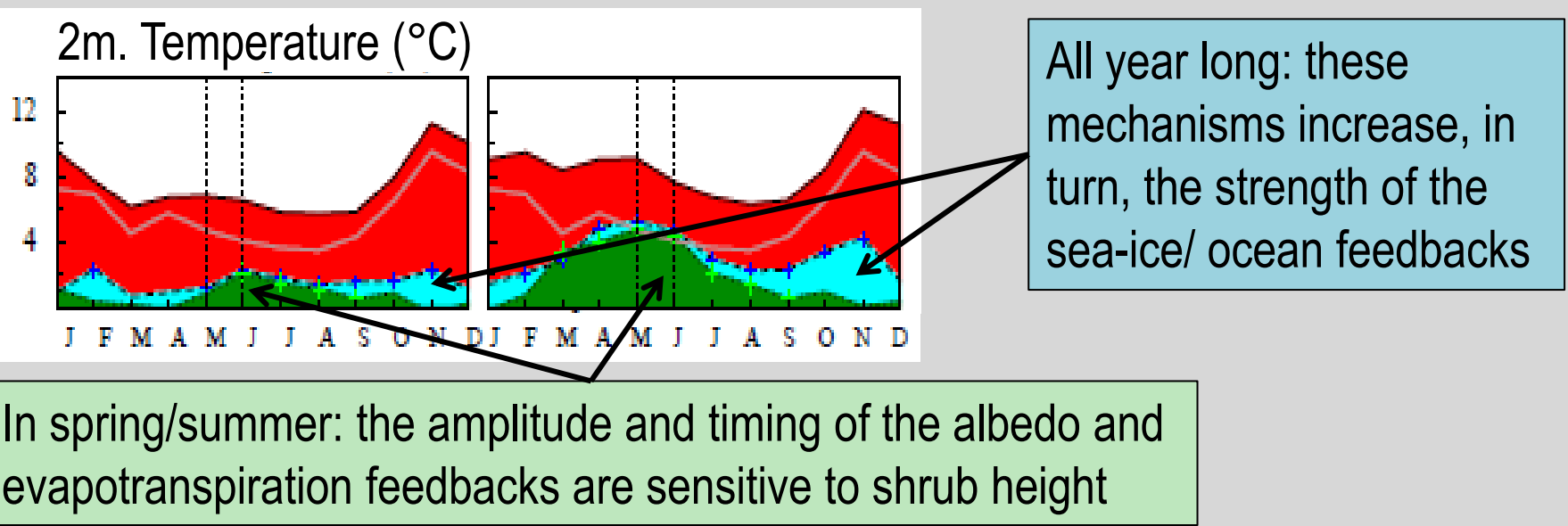
### Albedo feedback



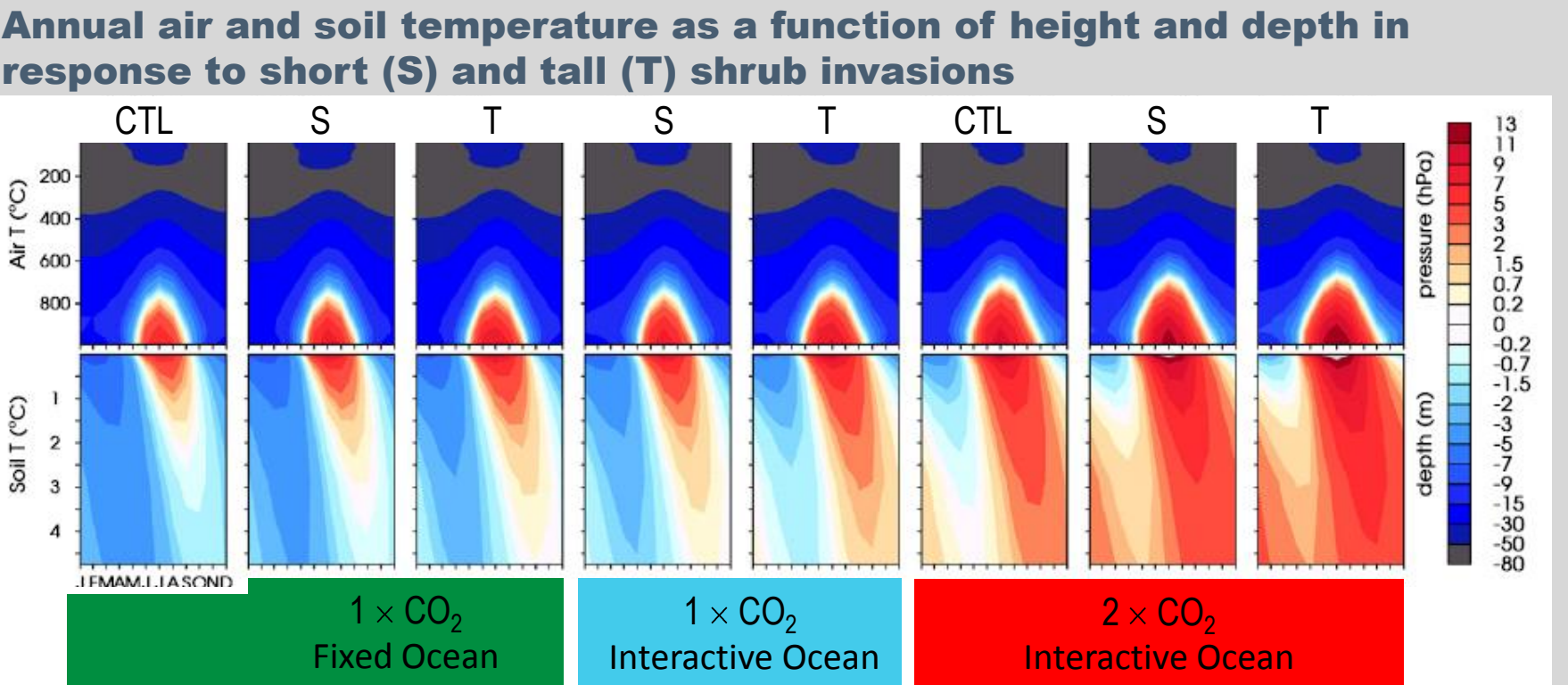
### Evapotranspiration feedback



### In consequence, the warming is more important in the tall shrub case



### Tall shrubs increase permafrost vulnerability



- The active layer thickness (thaw depth) deepens with the invasion of shrubs, and with IO. The below-freezing season shortens.
- When shrub expansion is paired with a warming ocean and increases CO<sub>2</sub>, the refreezing of the soil occurs only in the top meter. Below that, the soil no longer freezes, even in winter, and the heat content of the soil increases overall.

## Conclusions

- Shrub expansion leads to substantial atmospheric heating through two feedbacks (albedo and evapotranspiration)
- The strength and timing of these feedbacks depend highly on shrub height
- They impact, in turn, the strength of the indirect sea-ice/ocean feedbacks contributing to additional regional warming
- Finally, tall shrubs systematically warm the soil, deepen the active layer, and destabilize the permafrost more substantially than short shrubs